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(54) CDMA cellular communications with multicarrier signal processing

(57) According to the present invention, an improved CDMA receiver for receiving spread-spectrum-modulated signals is provided. In the improved receiver, a multicarrier signal processor (201) is positioned. The multicarrier signal processor includes a controller (307) for analyzing an incoming multicarrier signal. At least one signal modifier (35N) communicates with the controller, such that the controller directs the signal modifier to attenuate at least one carrier signal which is not spread-spectrum-modulated.

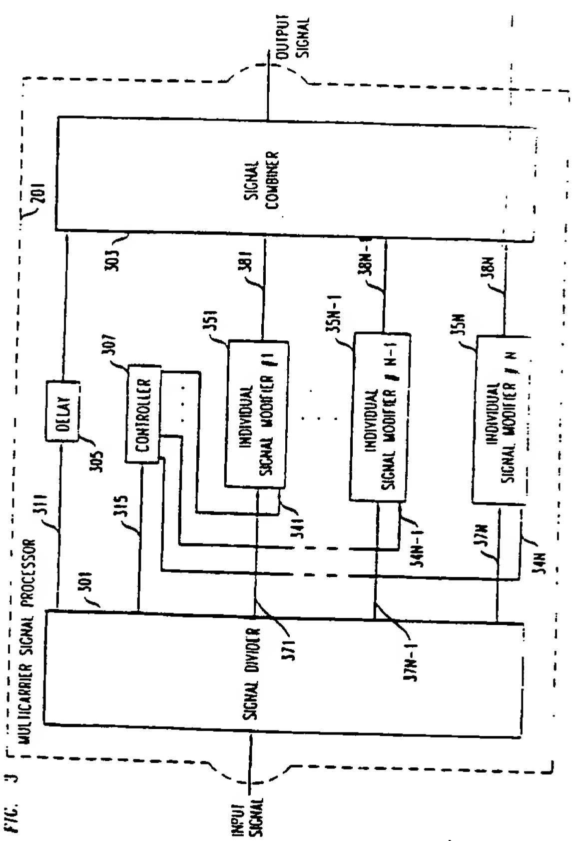

FIG. 3

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CDMA applications, the carrier signals of interest are low-power signals which are spread over a wide frequency range

FIG. 7 schematically depicts the spectral content of a typical multicarrier signal having no spread-spectrum-modulated signals. The multicarrier signal comprises nine constituent carrier signals, labeled S1 to S9, each of which is situated in a distinct frequency band. The dynamic range of the multicarrier signal is 70 dB (the difference in magnitude between the strongest constituent carrier signal, S_3, and the weakest constituent carrier signal, S_5). Using the multicarrier signal processor of the present invention, the dynamic range of the multicarrier signal in FIG. 7 is reducible by 40 dB, as shown in FIG. 8, by attenuating the power of signals S_3 and S_6 by 20 dB and boosting the power of signal S_5 by 20 dB. As a result, the dynamic range of the processed signal of FIG 8 is 30 dB.

Multicarrier signal processor 201 is typically employed in radio receiver front-end 100 to reduce the dynamic range of a group of P carrier signals of a multicarrier signal. For CDMA applications, multicarrier signal processor 201 is employed in a CDMA receiver to substantially reduce or eliminate signals which are not spread-spectrum-modulated. The radio receiver front-end generally comprises antenna 101, bandpass filter 105, multicarrier signal processor 201, amplifier 107, mixer 117, and local oscillator 125. The radio receiver front-end components are selected from any components or group of components which perform the stated functions, and will not be described in detail. Further description of radio components such as those used in receiver front-end 100 is found in Hickman, Newnes Practical RF Handbook, (Newnes, Oxford), c. 1993, the disclosure of which is incorporated by reference herein.

CDMA cellular communications systems employ CDMA radio receivers incorporating radio receiver front end 100 at several positions within a system. FIG. 9 depicts cellular communications system 800, partitioned into a number of geographically distinct areas called cells. In an exemplary embodiment, the CDMA cellular communication system is a direct sequence CDMA system. Cell 810 is schematically depicted as a hexagon, however, in practice a cell typically has an irregular shape depending upon the topography of the terrain serviced by the cellular system. Within the cell 810 is provided a cell site 820 which generally includes a base station 822 cooperating with an antenna 824. Radio receiver front end 100 is typically incorporated within the base station of cell site 820. Wireless terminals 840 communicate with cell site 820 via radio links. As used herein, the expression "wireless terminals" refers to any communications device which receives or transmits an electromagnetic signal through the atmosphere including, but not limited to, mobile telephones, pagers, and personal communicators.

Cell site 820 optionally communicates with a mobile telecommunications switching office (MTSO) 850, also known as a mobile switching center (MSC). The MTSO typically comprises a large switch (e.g., the 5ESS ® switch available from AT&T Corp.) that routes call to and from wireless terminals in the cellular system and, if necessary, to and from the public switched telephone network (PTSN) via a local office switch 860. Local office switch connects to the toll office, as shown. Detailed descriptions of cellular communications systems are found in Lee, Mobile Cellular Telecommunications Systems, (McGraw-Hill, N.Y.), c. 1989, Lee, Mobile Communications Design Fundamentals, (Wiley-Interscience), c. 1993, Transmission Systems For Communications, (Bell Telephone Laboratories, NJ), c. 1982, Rey, Ed. Engineering and Operations in the Bell System, (AT&T Bell Laboratories, Murray Hill, N.J.), c. 1983, and Young, Wireless Basics, (Intertec, Chicago), c 1992, the disclosures of which are incorporated herein by reference.

In the frequency range of interest, R, a multicarrier signal typically comprises a plurality of carrier signals with greatly disparate relative powers, i.e., a signal with a large dynamic range. Large dynamic range multicarrier signals negatively impact the performance of numerous system components with limited dynamic ranges such as mixers, amplifiers, and analog-to-digital converters. For example, when the physical dynamic range of mixer 117 is less than the dynamic range of the multicarrier signal, mixer 117 can introduce intermodulation products into the multicarrier signal. The intermodulation products combine with the carrier signals, creating a distorted output. Multicarrier signal processor 201 mitigates such problems in an exemplary embodiment by analyzing the multicarrier signal to determine the relative power of each of the constituent carrier signals. Based on the analysis, the multicarrier signal processor targets one or more of the constituent carrier signals whose power is beyond a particular range, the range being preset or determined from the multicarrier signal analysis. The multicarrier signal processor samples the multicarrier signal and sends at least one sampled multicarrier signal to a signal modifier which changes the phase and/or amplitude of the targeted constituent carrier signal. The targeted constituent signal is selected from an individual frequency band or a block or frequency bands, depending upon system needs. The modified signal is injected back into the unmodified multicarrier signal in a feedforward architecture. In this manner, the modified signal interacts with the corresponding unmodified constituent carrier signal to reduce the overall dynamic range of the multicarrier signal.

Multicarrier signal processor 201 reduces the dynamic range of a multicarrier signal in an exemplary embodiment depicted in FIG. 3. FIG. 3 depicts a block diagram of the processor 201, which comprises amplifier 390, signal divider 301, signal combiner 303, delay 305, controller 307, and one or more individual signal modifiers, represented by 35N. As used herein, N represents the number of individual signal modifiers in a given embodiment. While there can be any number, N, of individ-

nal upon which they act. Delay 305 and the phase shift imparted by each individual signal modifier must be carefully coordinated so that signal combiner 303 effectively performs a vector addition of all of the signals which enter it. In other words. if individual signal modifier 35N is to attenuate a given carrier signal. delay 305 must be set so that the multicarrier signal through signal path 311 and the isolated and modified signal through individual signal modifier 35N arrive at signal combiner 303 at the same time. In the case of signal attenuation. the phase of the output signal from the individual signal modifier is shifted 180° relative to the phase of the unmodified carrier signal. so that the two signals destructively interfere.

Alternatively. delay 305 is eliminated from signal path 311 and a negative delay element is inserted in signal paths 381. 38N-1. 38N. Negative delay elements. such as negative group delays. create signals which appear to have propagated a shorter distance than the actual path length by imparting a positive phase slope to the signal. The use of negative delay elements in signal paths 381. 38N-1. 38N. reduces the loss of the unmodified multicarrier signal in signal path 311. Since. in an exemplary embodiment. the majority of the signal strength traverses signal path 311. the overall loss in the multicarrier signal processor is reduced through the use of negative group delays. Exemplary negative group delays are described in U.S. Patent 5.291.156. the disclosure of which is incorporated by reference herein.

For the case of carrier signal amplification. the delay 305 is identical, since the time through the signal paths is the same. However, the phase of the modified carrier signal from the individual signal modifier is adjusted. relative to the phase of the respective unmodified carrier signal. so that the two signals are constructively added.

Individual components of multicarrier signal processor 201 will now be described with reference to FIGS. 4-6. FIG. 4 schematically depicts an individual signal modifier 35N for use in the multicarrier signal processor. Each individual signal modifier, i.e.. individual signal modifier 351, 35N-1, and 35N, isolates a targeted carrier signal and modifies its phase and/or amplitude in preparation for being injected back into the unmodified multicarrier signal. The individual signal modifier of FIG. 4 comprises mixer 401. bandpass filter 403. phase-shifter 405. amplitude modifier 407. mixer 409. amplifier 411 and programmable synthesizer 413.

A sample of the multicarrier signal enters mixer 401 from signal path 37N. Mixer 401 mixes down the multicarrier signal, so that bandpass filter 403 can isolate the constituent carrier signal targeted for modification by controller 307. Programmable synthesizer 413 directs mixer 401 to shift the incoming multicarrier signal such that the targeted carrier signal is positioned at the pass frequency of bandpass filter 403. In this manner. the carrier signal targeted by controller 307 is isolated from the multicarrier signal by bandpass filter 403. The carrier signal that is isolated by bandpass filter 403 will be referred to as an isolated carrier signal. Bandpass filter 403 is typically a high Q bandpass filter with a passband equal to the frequency bandwidth of the targeted signal or block of signals

The isolated carrier signal exits the bandpass filter and is fed to phase shifter 405. Phase-shifter 405 selectively changes the phase of the isolated carrier signal by a given number of degrees. For example. by shifting the phase of the signal such that the signal is 180° out of phase with the unmodified carrier signal. the modified carrier signal destructively interferes with the unmodified carrier signal. When the modified signal is to constructively add with the unmodified carrier signal. the phase shifter is set such that the modified and unmodified carrier signals are in phase with one another. In this manner. the modified isolated carrier signal from the individual signal modifier. when injected back into the multicarrier signal by signal combiner 303. interacts with the corresponding unmodified carrier signal by destructively interfering or constructively adding with the unmodified carrier signal to reduce the overall dynamic range of the multicarrier signal. Phase-shifter 405 is provided with either a fixed phase shift. i.e.. a phase shift preset for a given number of degrees. or it is provided with a variable capability that is controlled by controller 307. In an exemplary embodiment. phase shifter 407 is programmable such that it adjusts the phase of the signal according to its frequency.

Following phase shifter 405. the isolated carrier signal next enters amplitude modifier 407. While amplitude modifier 407 is illustratively depicted as an attenuator. the modifier is selected from elements which can amplify. attenuate. or alternatively amplify or attenuate an incoming signal. e.g.. amplifiers which are capable of both attenuating and amplifying. The amount by which signal modifier 407 either amplifies or attenuates the isolated carrier signal is selected to be either fixed or variable. depending upon system considerations. When the amount is variable. controller 307 directs the amount of attenuation or amplification to be produced by amplitude modifier 407.

While each individual signal modifier can either attenuate or amplify the isolated carrier signal, in an exemplary embodiment signals are only attenuated. Attenuation of signals tends to result in an overall better noise figure for the multicarrier signal processor. In this embodiment. amplitude modifier 407 is selected to be an attenuator. Typically, the attenuator attenuates the isolated carrier signal by approximately 20 to 30 dB.

Following signal modification, the modified isolated carrier signal enters mixer 409. Mixer 409 mixes up the modified isolated carrier signal, as directed by programmable synthesizer 413. to the frequency band in which the carrier signal resided prior to mixing down by mixer 401. The modified isolated carrier signal is amplified by amplifier 411. then output to signal combiner 303 via path 38N.

Following vector combination in signal combiner 303. the modified multicarrier signal is optionally input to

selecting carrier signals with power levels above the threshold limit:
modifying the carrier signals with power levels above the threshold limit. and
combining the modified carrier signals with the unmodified multicarrier signal such that the carrier signal is attenuated.

3. An apparatus for attenuating carrier signals in a multicarrier signal comprising at least one spread-spectrum-modulated signal and other carrier signals. comprising:

a receiver (200) for receiving a multicarrier signal comprising at least one spread-spectrum-modulated signal and other carrier signals:
a multicarrier signal processor (201) communicating with the receiver. the multicarrier signal processor. the multicarrier signal processor having a control portion with a threshold limit set for power levels beyond those of spread-spectrum-modulated signals:
at least one signal modifier (35N) communicating with the controller. for modifying at least one carrier signal with a power level above the threshold limit: and
a signal combiner (303) communicating with the at least one signal modifier for combining the modified carrier signal with the unmodified multicarrier signal such that at least one carrier signal with a power level above the threshold limit is attenuated.

4. A CDMA communications system incorporating the receiver of claim 1.

5. A CDMA communications system incorporating the apparatus of claim 3.

FIG. 3

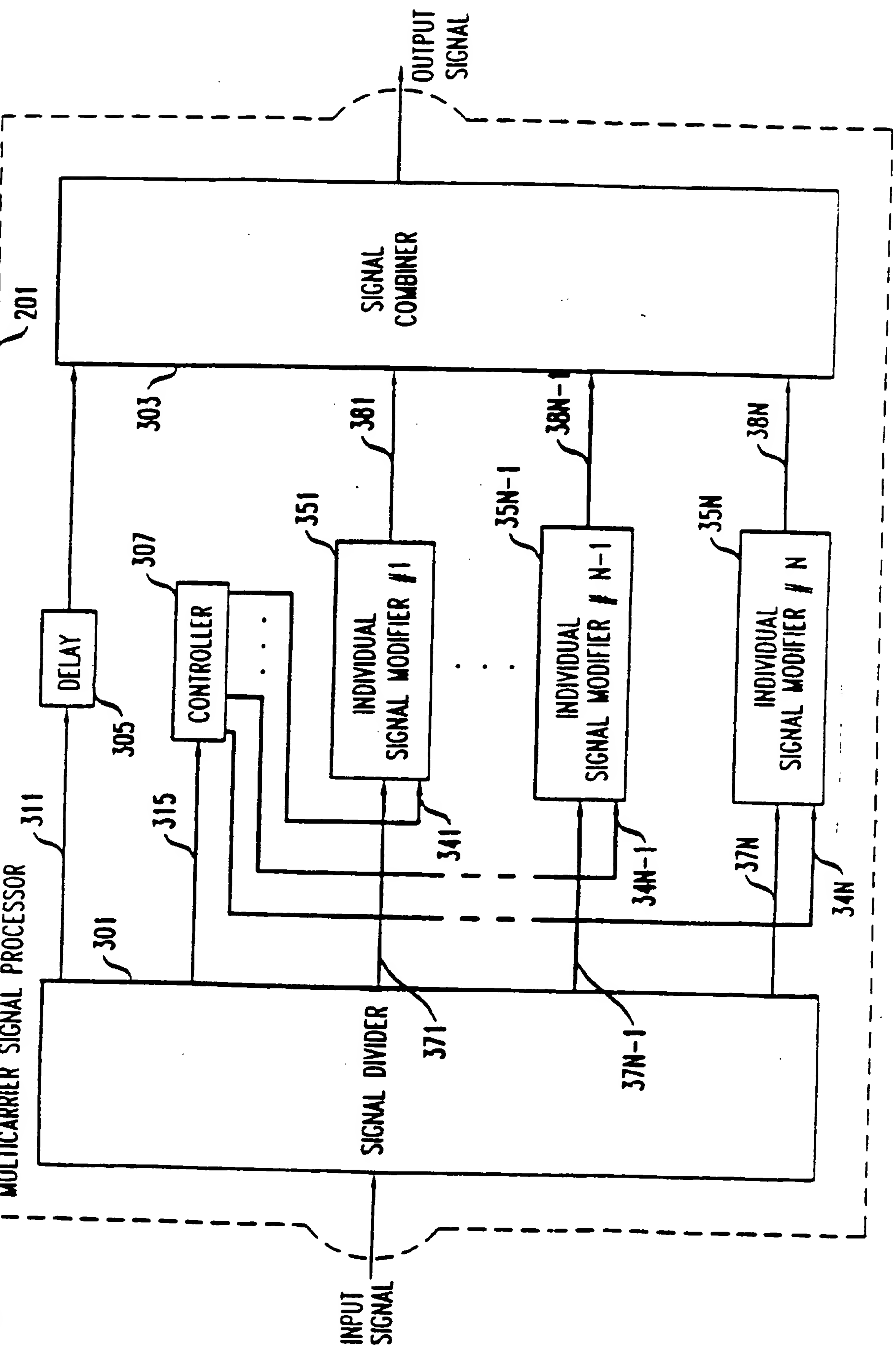
MULTICARRIER SIGNAL PROCESSOR
201
INPUT SIGNAL
OUTPUT SIGNAL
SIGNAL DIVIDER
SIGNAL COMBINER
DELAY
CONTROLLER
INDIVIDUAL SIGNAL MODIFIER #1
INDIVIDUAL SIGNAL MODIFIER # N-1
INDIVIDUAL SIGNAL MODIFIER # N
301
303
305
307
311
315
341
34N-1
34N
351
35N-1
35N
371
37N-1
37N
381
38N-1
38N

FIG. 6

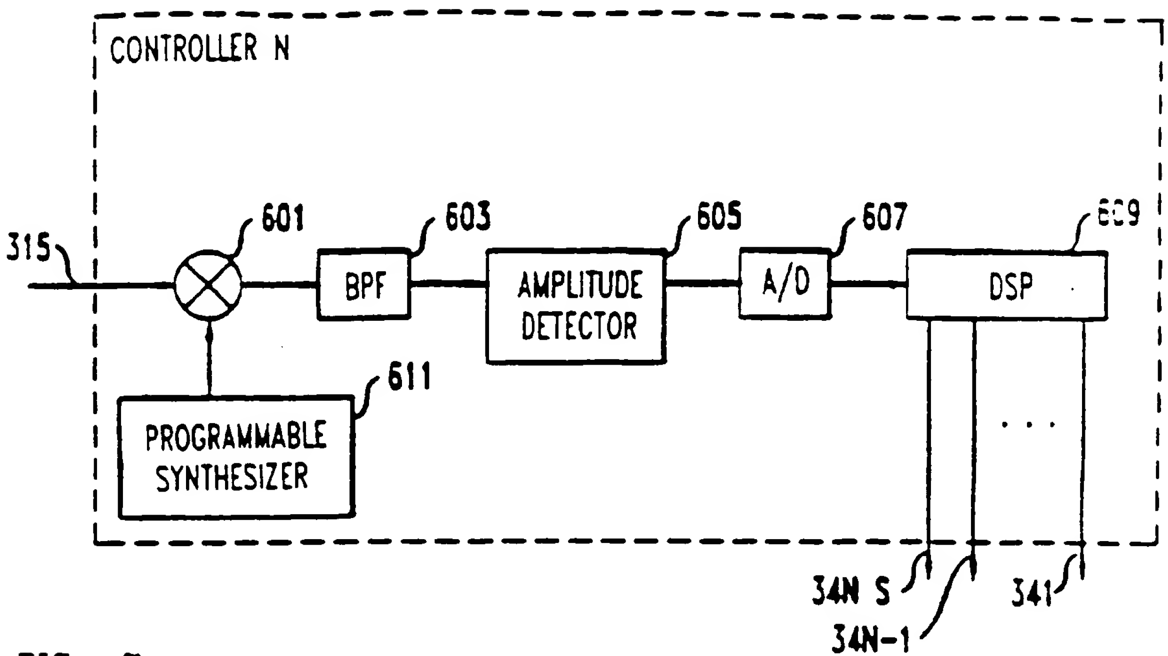

FIG. 7

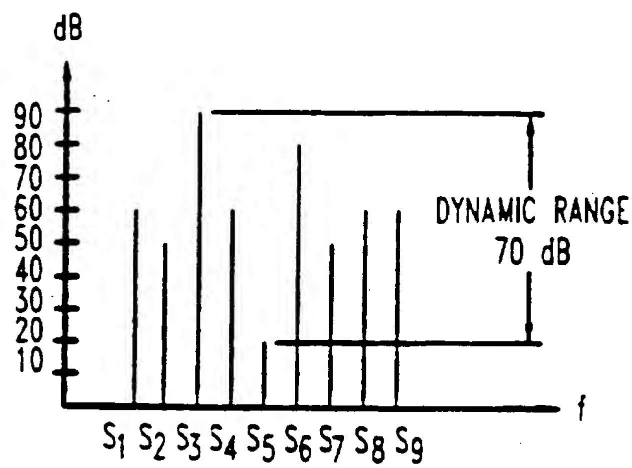

FIG. 8

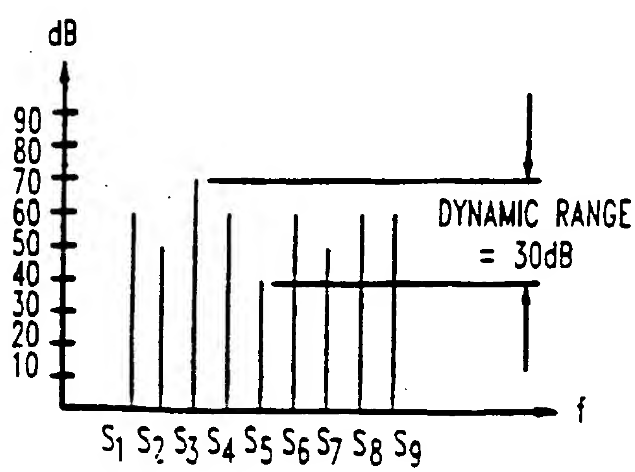

FIG. 10